**Taphonomic Signatures of Bald Eagles (*Haliaeetus leucocephalus*) on Avian Prey Bones from Boundary Bay, British Columbia, Canada**

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This study investigated the damage that bald eagles (*Haliaeetus leucocephalus*) left on an accumulation of waterfowl bones in Boundary Bay, British Columbia. Avian sterna were identified quantitatively and qualitatively to the species level, most belonging to the order Anseriformes, family Anatidae. We suggest that avian sterna with large puncture holes, sharp breaks, bone flakes, cracks and jagged margins are identifiable and diagnostic to eagle feeding. This is relevant to archaeological situations where raptor-produced bone dumps could be confused with anthropogenic refuse middens. The study has two main results: 1) determination of species composition of kills from an eagle-produced bone dump and 2) description and quantification of the frequency and type of raptorial predator damage to the sterna of the avian prey.

***Keywords***: ANATIDAE STERNUM, TAPHONOMIC SIGNATURE, SPECIES IDENTIFICATION, BALD EAGLE, RAPTOR PREDATION, MODERN, BONE MIDDEN, BOUNDARY BAY

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## Introduction

The differentiation between human and natural middens has been an ongoing concern for archaeologists (Behrensmeyer, 1991; Erlandson and Moss, 2001; Erlandson et al., 2007; Howard, 1929; Laroulandie, 2002; Lyman, 2002). Complex refuse middens are often found at coastal British Columbian and other archaeological sites and are attributed to human food disposal activities (Fladmark, 1986; Kusmer, 1994). Birds of prey, including bald eagles (*Haliaeetus leucocephalus*), also create accumulations of discarded bones, pellets and partial carcasses from their kills. Hunted and scavenged prey remains form refuse heaps as eagles perch and drop undesirable parts of their prey to the ground. Thus, feeding sites of avian raptors that are excavated can be mistakenly taken for cultural food remains. The presence of beak and talon scars on victim bones left by raptors in this study may help differentiate between anthropogenic middens and natural accumulations, specifically from birds of prey.

A heap of animal bones and tissues from a bald eagle feeding site was collected in Boundary Bay (Latitude 49.024440, Longitude -123.046944), south of Tsawwassen, British Columbia in June 2007. We examined this material to identify species composition and examine the apparent damage on the prey bones. The osteological sample was non-cultural and modern.

From our first impressions of the eagle prey remains, it was clear that the assemblage had a preponderance of waterfowl bones present. This was unusual since the diet of bald eagles in the Pacific coastal area is commonly noted as being dominant in fish (Watson, 2002; Watson et al., 1991). However, the sample is not unexpected. Although the main food source of British Columbian bald eagles is fish, their predation strategy is flexible, opportunistic and specific to location and time of year (Blood and Anweiler, 1994). Knight et al. (1990), for example, documented bald eagle diets from western Washington, the San Juan Islands and the Olympic Peninsula where the majority of bald eagle prey remains were birds, constituting 53% of the specimens. Avian prey are the main food source for eagles in other locations as well (Cash et al., 1985).

Previous studies have tried to distinguish human-produced and raptor-produced bone accumulations. There has been concern with accurately interpreting anthropogenic versus natural bone assemblages based on the proportion of wing bones to leg elements present (Bochenski et al., 1999; Bovy, 2002; Bramwell, 1987; Ericson, 1987; Livingston, 1989). This wing-to-leg bone ratio that is intended to reveal human or natural depositional origin is not applicable to all avian species due to differences in species morphology such as degree of bone density and pneumatization (Livingston, 1989) or to varied environmental preservation and diagenesis factors.

There have also been a handful of studies that discuss the modifications left by avian raptors on prey bones (Bochenski 2002; Erlandson et al., 2007; Hockett, 1991; Worthy and Holdaway, 1996). Bochenski et al. (1999) have already proposed a taphonomic signature that the golden eagle (*Aquila chrysaetos*) and likely other diurnal raptors leave on prey bones. Our observations support Bochenski's work and can help zooarchaeologists, taphonomists and paleontologists identify the damage from diurnal raptors with greater confidence.

*Research objectives*

Five objectives framed our study:

1. To determine the species composition of a sample of prey remains found at an eagle feeding site in Boundary Bay, British Columbia;
2. To select the best bone element as a standard to ID as many species as possible from eagle food remains;
3. To examine waterfowl sterna from the family Anatidae (ducks, geese and swans) from the sample and record the type and extent of predator damage;
4. To provide data to establish the origin of avian bones for archaeological research; and
5. To conduct a replicable modern experiment for future zooarchaeological research on the taphonomy of family Anatidae. Find a modern analog for process that could have occurred in the past…

## Materials and methods

*Sample location*

Resident and migratory bald eagles (*Haliaeetus leucocephalus)* hunt at Boundary Bay. Hundreds of bird species can be found in the eelgrass, mud flats, estuaries, salt marshes and swamps of Boundary Bay and the site is a major stop-over ground on the Pacific Flyway migration route. Eagles at this location have been known to kill and eat various avian species including scaups, scoters, loons and sea gulls. There are a number of man-made navigation tower platforms situated in the water in Boundary Bay, which act as natural perches that likely create predation opportunities for eagles to target seabirds and other waterfowl. Ornithologist Dr. Rob Butler and archaeologist Dr. Jon Driver collected prey remains from a bald eagle feeding site located at one of these towers in Boundary Bay in June 2007. These remains had been accumulating for a period of four years. The mesh platform from which the bone accumulation was collected sits about 3-4 meters above sea level with a long metal pole extending up from the platform. The mesh platform had rectangular holes of approximately 2 x 8cm. At any given time, one or more eagles can perch on the metal pole or mesh platform of the tower to eat their prey. This feeding behaviour leaves an accumulation of partial carcasses on the wire meshing. Butcheries consisting of piles of bones from eagle kills have been used to document eagle diet and are not uncommon in nature, especially underneath roosts and nests (Knight, 1990; Seguin et al., 1998; Smith, 1985; Watson, 2002; Watson et al., 1991).

The original intention of this study was to identify the waterfowl that were hunted by eagles, as part of a larger research program on waterfowl ecology. The collectors selected what appeared to be the most common identifiable skeletal elements from a large mass of bones, feathers, soft tissue, sediment and feces. Thus, the sample examined here did not contain all skeletal elements that were present in the original bone dump.

*State of preservation*

The animal remains were in various states of preservation and included bones, feathers and some desiccated tissues. According to Behrensmeyer's 'stages of bone condition' (1978), our sample rates as a Category 1: some bone surfaces showing cracking, usually parallel to the orientation of collagen fibres as well as articular surfaces that may show cracking in a mosaic pattern.

We immediately observed that some fragile bones were broken and that many bird sterna appeared to have predator damage. On closer examination, there were small stones and three partial fish skeletons found in the sample. It is worth noting that specimens of a small size such as fish bones, small vertebrates and mollusks are probably under-represented in the midden due to the metal mesh platform. Although the study sample was of recent times, the findings presented here can be applied to ancient fossilized bones found in archaeological deposits.

*Use of sterna for identification and damage observations*

After our initial examination of the prey bone dump we decided to focus on the waterfowl sterna for identifications. The sternum is a large bone in birds that can be salvaged easily from bone accumulations due to its distinct shape. We chose the sternum as an appropriate bone element for species identification because the sterna were numerous and appeared distinctive morphologically (see *Table 2* and *Table 3*).

Furthermore, the sterna of waterfowl present in the area are too large to fall through the spaces in the mesh platform, whereas other diagnostic elements (e.g. wing and leg bones) could pass through. The sternum thus provides the best chance of obtaining a representative sample of the waterfowl brought to the perch by eagles.

The minimum number of individuals (MNI) based on sterna was 101, although this count is conservative and may underestimate the true value (Holtzman, 1979). After cleaning all crania found in the sample (n= 38), we decided the cranial morphology appeared too similar to be identified to species without difficulty; crania were also fragile and badly damaged. The sterna of waterfowl are a major source of osteological variation that taxonomists have used to establish genera and species phylogenetic groupings (Woolfenden, 1961). The bones of the upper limbs (coracoid, humerus, radius, ulna, capometacarpus) were also very numerous in the sample; however, they did not display the obvious cracking and beak marks of bone modification seen clearly on the sterna.

*Cleaning*

Over 22 hours of bone cleaning was completed in two steps: 1) dry cleaning, and 2) wet cleaning. Dry cleaning involved picking off tissues, feathers, sediment and feces with tweezers and soft brushes. This was followed by wet cleaning where sterna specimens were immersed and boiled in 250ml of bleach per 4L of water for at least 20 minutes to achieve sterilization. Adhering tissues were removed with tooth brushes, chopsticks, tweezers, scissors and scalpels. Care was taken to avoid damaging fragile bones during cleaning, and metal implements were used only where necessary.

*Species identification of sterna: ecological background*

We conducted species identification of the waterfowl sterna in three steps. Firstly, ecological literature was consulted to establish possible species in our sample which are known to migrate through or inhabit Boundary Bay. The waterfowl species present in the regions coastal habitats were determined. Ecological data were used to establish all feasible bird species preyed upon in the bald eagle habitat area (Baron and Acorn, 1997; Campbell et al., 1990, Butler and Campbell, 1987; Murray, 2006; Wheeler, 2003).

*Species identification of sterna: quantitative analysis*

Quantitative identification of species possibilities was carried out by the use of five or more measurements on each sternum in our sample, taken with calipers. We followed measuring protocol outlined in Oates et al. (2003) to employ a process of elimination to determine species possibilities.

These measurements included:
A: Maximum length from carinal apex of keel to end of xiphal or caudal area;
B: Maximum length from the carinal apex of keel to ventral manubrial spine;
C: Width of keel measured at the intercostal space between the 7th and 8th costal process;
D: Narrowest width of the sternum between the sternal notches; and
H: The minimum width of the posterior lateral process.

*Species identification of sterna: qualitative analysis*

After a number of species possibilities were identified for each sterna from metric traits, qualitative identifications took place. Qualitative identifications were based on published descriptions, drawings and pictures of sternal morphological characteristics distinctive to Northwest coast waterfowl genera and species (Gilbert et al., 1981; Oates et al., 2003; Olsen, 1979; Woelfle, 1967; Woolfenden, 1961). In addition, the zooarchaeology osteological collection at Simon Fraser University was used for further comparative analysis. All sterna were reviewed qualitatively at least twice to determine species, genus or assign unknown status. If sufficient species identification agreement could not be established between both quantitative and qualitative data, the sternum was not identified.

Species recognition based on a single bone element requires a rigorous program of identification. Based on the above research, neither quantitative nor qualitative analysis should be used on its own when examining sterna. Current and historical ecological information specific to the area of study aids to eliminate species possibilities. It is efficient to take quantitative osteological measurements first to narrow species possibilities quickly. However, measurements alone cannot provide reliable species determinations, especially when the sterna are damaged or fragmented.

*Frequency of damage type on prey sterna*

We compiled a record of predator damage by taking digital photographs of all sterna in dorsal, ventral and lateral views. A qualitative description of bone modification trauma noted on each of the sterna was recorded. The frequency of each trauma type seen in the sample was calculated (*Table 1*). The categories of damage included: damage to keel, ragged punctures, caudal area broken or missing, lateral process broken or missing, sterno-corocoidal process broken or missing, costal margin broken or missing and anterior area broken or missing.

## Results

*Predator damage*

There is a unique signature left on avian sterna by the feeding behaviour of bald eagles. The signs were relatively obvious, prevalent and appeared to be made with a good deal of impact force. Bald eagle damage on sterna manifested in two main ways: 1) irregular ragged bone edges, and 2) perforated holes. Ragged bone edges are characteristically cracked, rough, angular, with broken flakes sometimes still attached. These sharp jagged edges often occur along terminal bone edges (see *Figures 1-3*). It appears that only a powerful thrust by a sharp, pointed object could have produced the puncture holes through the sterna bones. Also, long and thin irregular breaks in the bone were seen on seven sterna and could have resulted from the ripping action of eagle talons. Sterna markings were not frayed, eroded or smooth and showed no abrasion or polishing. The prey remains contained no regurgitated pellet material since no gastric etching or disintegration could be discovered. Other raptors with hooked beaks and talons including hawks, falcons, osprey, kites and harriers could leave similar markings on their prey, though this was not examined here.

*Figure 1. Severe and forceful eagle damage*

*Figure 2. Ragged punctures and sharp cracked edges*

*Figure 3.  Ragged punctures in the keel*

As seen in *Table 1*, damage to the sternal keel was commonly encountered and occurred in the highest frequency throughout the sample (77%). Ragged edges were also typically observed on the caudal area of the sterna. The most distinctive eagle signature was the punctures that were seen on the majority of sterna (74%). These holes ranged in size from approximately 3-15mm.

*Table 1. Quantification of damage type on sterna*

| **Damage type category** | **Number of sterna affected** | **Percent** |
|---|---|---|
| Damage to keel | 78 | 77% |
| Puncture holes (1+) | 75 | 74% |
| Caudal area broken or missing | 57 | 56% |
| Lateral process broken or missing (1) | 45 | 45% |
| Sterno-corocoidal process broken or missing (1) | 45 | 45% |
| Lateral process broken or missing (2) | 25 | 25% |
| Costal margin broken or missing (1) | 21 | 21% |
| Sterno-coracoidal process broken (2) | 13 | 13% |
| Anterior area broken or missing | 7 | 7% |
| Costal margin broken or missing (2) | 5 | 5% |

*Species composition of prey remains*

Bird species from the family Anatidae were the dominant taxa represented in the eagle ‘midden’. Resident and migratory bald eagles in Boundary Bay have been known to kill and eat various avian species including scaups, scoters and sea gulls, which were all found in the accumulation (Murray, 2006; Butler and Campbell, 1987). *Table 3* shows that the highest number of identifiable species were surf scoters (25%) followed by long-tailed ducks (19%), white-winged scoters (18%), greater scaups (18%) and black scoters (10%). All the above-named ducks are diving varieties adapted to foraging in open water habitats like the area around the eagle feeding tower in Boundary Bay. It is possible that these diving ducks make easy kills for eagles when they surface, especially given the high visibility of prey from the perch location. In addition, the heavy wing bones of diving ducks affect their ability to take off, which may delay their escape from predators. Remains of three Actinopterygiian fish of unknown species, one gull (*Larus glaucescens*) and fragments of bivalves were also present in the sample. The bivalves were probably in prey stomach contents and not food of the bald eagles themselves.

*Table 2. Waterfowl in sternum sample*

| **Species** | **Number of sterna** | **Percent (to nearest 1)** | **Percent of species identified** |
|---|---|---|---|
| *Melanitta perspicillata* (Surf Scoter) | 18 | 18% | 25% |
| *Melanitta fusca* (White-winged Scoter) | 13 | 13% | 18% |
| *Melanitta nigra* (Black Scoter) | 8 | 8% | 10% |
| *Melanitta spp.* (Scoter genus) | 20 | 20% | n/a |
| *Aythya marila* (Greater Scaup) | 13 | 13% | 18% |
| *Aythya affinis* (Lesser Scaup) | 2 | 2% | 3% |
| *Clangula hyemalis* (Long-tailed Duck) | 14 | 14% | 19% |
| *Lophodytes cucullatus* (Hooded Merganser) | 2 | 2% | 3% |
| *Bucephala albeola* (Buffelhead) | 1 | 1% | 1% |

| | | | |
|---|---|---|---|
| *Histrionicus histrionicus* (Harlequin Duck) | 1 | 1% | 1% |
| *Anas platyrhynchos* (Mallard) | 1 | 1% | 1% |
| Unknown | 8 | 8% | n/a |
| | | | |
| Total | 101 | 100% | |
| Total ST identified to spp. | 73 | 72 % | |

**Discussion**

*Eagle damage*

The vast majority of sterna (94%) showed distinctive damage. There was a clear and consistent pattern across the sample that includes splintered edges, angular cracks and puncture holes. The trauma can be traced to the action of eagles and we believe the damage attributes can be generalized to diurnal raptors. We are confident in discrediting the scenario of bone damage being caused by human hunting and gunshots. No shotgun pellets were found and the jagged holes in the sterna were not of uniform size and shape. Bald eagles have been observed feeding at the tower site in Boundary Bay. In addition, other small raptors or predatory sea birds seem unlikely to have caused such large and forceful damage to prey sternums. In agreement with our results, it has been documented that bald eagle feeding behaviour includes stripping breast meat off the sternum with the beak (Bochenski, 2002; Herrick, 1924; Hockett, 1996). Breast muscles of birds are well developed for flight and are the biggest in their bodies; these tissues would be preferred over the low meat content of wings and legs. Birds feeding on other avian species target certain body areas with a high degree of specificity. Our observations are consistent with work by Oliver and Graham (1994) who convincingly examined mammal versus bird scavenging patterns seen on dead ice-trapped American coots. They showed bird scavengers methodically stripped the neck and breast meat of coots clean and left the rest of the body uneaten. The Boundary Bay waterfowl remains fed on by eagles were also often found in articulation with no meat left on the sterna. In contrast, scavenging mammals took entire birds or left carcasses in disarray, with residual flesh and frequently with broken limb bones.

*Developmental holes*

Five sterna had developmental holes of various sizes. These were oval, rounded, had clean smooth edges and occurred in localized areas of the bone (*Figures 4* and *5*). These foramen are perhaps due to poor nutrition, disease or genetic abnormalities in the waterfowl. When the collection was reviewed, there was no evidence to suggest that any of the sterna were from young or juvenile birds that may have thinner developing bones. This agrees with excavations of a historical eagle nesting site by Erlandson et al. (2007) that found the vast majority of avian prey elements were from adult birds. The rounded edges of the holes are not due to digestive acid erosion since they occur in localized areas and because the sterna found in the sample collection are too large for an eagle to swallow whole. We did not observe similar pathologies in skeletons from the comparative collection; the relatively high frequencies of these bone abnormalities at Boundary Bay should be investigated further.

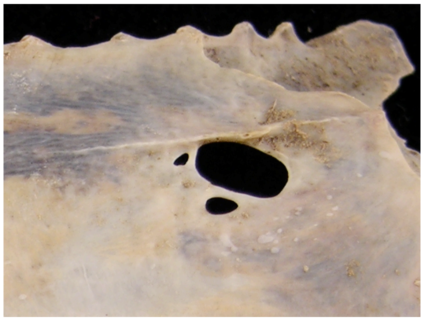

*Figure 4. ST 40: 3 developmental holes*

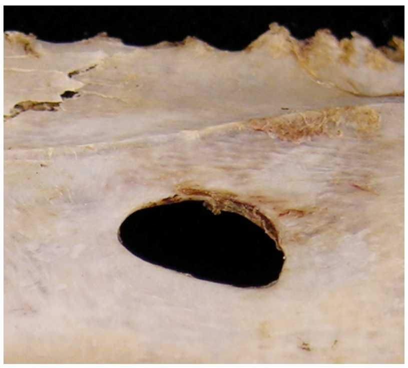

*Figure 5. ST 47: 1 developmental hole*

*Archaeological implications*

Identifiable raptor markings such as punctures of appropriate size, angular cracks and irregular ragged edges left on prey bones can help identify a natural non-cultural origin of bones. These markings are regarded as a signature that appears to be caused only by the force and impact of a hooked beak and talons of an avian raptor. In a wider context, the work here can be applied to taphonomic studies in archaeology that seek to determine whether bone modification and deposition is due to anthropogenic or natural causes.

Birds have been hunted by people and have served dietary, decorative, symbolic and economic uses throughout human history. There are numerous examples of feathers and bones from specific birds having a high cultural value (Gilbert et al., 1981). Avian species we found in our sample have also been recovered from Coast Salish archaeological sites in Boundary Bay and the surrounding area including: Tsawwassen, Beach Grove, Whalen Farm and Crescent Beach. Hobson and Driver (1989) identified birds found at archaeological sites in the Straight of Georgia. They included, among other taxa, the same species that were identified in our sternum sample. Waterfowl were hunted in the past by First Nations as sources of food and feathers in Georgia Straight. Hunting took place with various kinds of nets, snares, slingshots and from canoes (Hanson, 1991).

*Considerations for Future Research*

Taphonomic signatures that are diagnostic and specific to a group of animals can be identified and utilized. However, potential distinguishable predator signatures on prey bones should be considered and studied with due caution before they are categorized as unique to the exclusion of other damage possibilities. It would be informative to conduct a comparative study of the specific types of damage left by birds of prey, dogs, felines and humans on avian prey bones.

Other bone elements of the avian prey, such as long bones and vertebrae, may not demonstrate the taphonomic signature of diurnal raptors and the high frequency of damage as evidenced on the sterna. Bramwell et al. (1987) reported that every avian sternum and synsacrum from Ossom's Eyrie Cave, England, displayed damage but most limb bones were actually intact. It is known that eagles nested at this site. Bochenski et al. (1999) also showed that surface damage from the eagle *Aquila chrysaetos* on the long bones of bird prey was very low. He also states that beak impact traces may only be evidenced on some bone elements (Bochenski, 2002). The taphonomic signature seen on the sternum is very likely the result of raptor feeding behaviour focused on the breast meat of their avian prey's body coupled with the thinness of the bone on the sternum. More information is needed about precisely how diurnal raptors feed on avian prey to further support our results. Predator preferences for birds over fish for example, conceivably reflect food abundance and the specific hunting patterns of the individual.

*Conclusion*

This study has shown that avian prey remains can be attributed to the feeding actions of diurnal raptors. The characterization of the eagle taphonomic signature on avian sterna can be applied to bird remains that are excavated at archaeological sites. It is possible to avoid the misinterpretation of bird bone markings produced by raptors or humans. The question of natural or cultural origin of fossil bone accumulations encountered archaeologically is aided by taphonomic studies detailing recognizable patterns on bones from predatory and scavenging animals.

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